Suppose there be two solutions V and V_1. Then, from Green's theorem,

$$\iiint(V-V_1)\left[\frac{\partial}{\partial x}\left(\frac{\sigma\partial(V-V_1)}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{\sigma\partial(V-V_1)}{\partial y}\right)+\frac{\partial}{\partial z}\left(\frac{\sigma\partial(V-V_1)}{\delta z}\right)\right]dxdydz=-\iiint\sigma\left[\left\{\frac{\partial(V-V_1)}{\delta x}\right\}^2+\left\{\frac{\partial(V-V_1)}{\partial y}\right\}^2+\left\{\frac{\partial(V-V_1)}{\partial z}\right\}^2\right]dxdydz+\iint(V-V_1)\left[\frac{\sigma l\partial(V-V_1)}{\partial x}+\sigma m\frac{\partial(V-V_1)}{\partial y}+\sigma n\frac{\partial(V-V_1)}{\partial z}\right]ds \qquad (18)$$

The left-hand side is zero on account of the equation of continuity. The surface integral is taken over the surface composed of $r=a$ and $r=3.82a$. Over $r=a$, V and V_1 are both constants. Over $r=3.82a$, V and V_1 are sensibly constant, in view of the enormous conductivity there. Hence, over each surface, the integral is proportional to the corresponding value of

$$\iint\left[\sigma l\frac{\partial(V-V_1)}{\partial x}+\sigma m\frac{\partial(V-V_1)}{\partial y}+\sigma n\frac{\partial(V-V_1)}{\partial z}\right]ds \qquad (19)$$

This integral is zero: For, over $r=a$, σ is constant, and the integral is proportional to the difference between the total charges on the earth's surface for the two solutions, which difference is zero by the conditions of the problem. The integral (19) over the surface $r=a$ represents the difference of the total currents from the earth for the two solutions, so that this difference is zero; and, as a result, the difference between the total currents through $r=3.82a$, for the two solutions, must be zero. It follows from this last conclusion that the value of (19) over $r=3.82a$ is zero. Hence, the total surface integral in (18) is zero.

We thus conclude that the remaining triple integral in (18) is zero, and this necessitates that $V-V_1$ shall be, at most, a constant, since the triple integral is a sum of squares. Again, the constant must be zero, since $V=V_1$ over $r=a$. Hence, within $r=3.82a$, the two solutions V and V_1 are sensibly the same.

From the physical standpoint the significance of the above demonstration exists in the fact that the highly conducting layer acts as an electric shield, which prevents external agencies from doing more than produce a constant potential within. This, again, is of importance in showing us that the distribution of potential-gradient over the sphere $r=a$ has really resulted from the variable conductivity distribution assumed below the sphere $r=3.82a$, and is not a mere result of the conductivity distribution, and its concomitant charge distribution which our function (16) happens to predict for the extreme outer regions of the atmosphere ($r>3.82a$).

An interesting field of extension of the principles outlined in this article is to be found in the solar eclipse. We should expect that the sudden removal of the sun's rays from any part of the upper atmosphere would have the effect of decreasing the potential-gradient at the corresponding point on the earth's surface. This is in line with such experiments as have been made on the variation of the potential-gradient during the eclipse. Reverting to the crude illustration occurring at the beginning of this article, we may liken the removal of the sun's rays to the production of a dent on the inside of the outer conducting sphere figuring in the illustration.

RADIO DIRECTION CHANGES AND VARIATIONS OF AUDIBILITY.

By CARL KINSLEY and ALBERT SOBEY.

[Presented at the September meeting of the Institute of Radio Engineers, New York, N. Y., and published in their proceedings.]

SYNOPSIS.—The war afforded very good opportunity for experimenting with devices for discovering the source of wireless waves. This paper discusses experiments made with the radiogoniometer and with the audibility meter with a view to determining a possible relation between direction of source and audibility.

It is at once evident that variations of audibility and direction are in a large measure due to the changes in the uniformity of the transmitting medium. This is discussed to determine whether or not the observed discontinuities are explainable upon this basis. It is suggested that much is dependent upon the ionization of the atmosphere by sunlight and the consequent absorption of electrical energy, which would account for the greater radius of transmission at night; the existence of the reflecting Heaviside layer, at an altitude of about 80 km.; and the nighttime irregular character of the ionization at the base of the stratosphere, at about 10 km., forming variable reflecting surfaces for waves.—*C. L. M.*

INTRODUCTION.

The development of methods for the determination of the point from which radio signals originate was actively carried on during 1918. The radiogoniometer measurements played an increasingly important rôle during the fall of last year. It seemed probable that the so-called radio compass might be called on to an extraordinary extent to assist in the projected operations of the spring of 1919, when an extensive use of aircraft would make necessary an exact method of navigation for cloudy weather both by day and night.

There had been no opportunity, however, for an examination of the degree to which reliance could be placed upon that method of determining directions when the origin of the radio signals was known. During the winter and spring of 1919 we were fortunately able to carry on an extended series of measurements under the peculiarly favorable circumstances of widely separated stations operated by well-trained observers.

DISCUSSION OF PROBLEM.

It has been found that radio messages can be read at much greater distances than the previously existing theories of the transmission of electromagnetic waves had indicated as possible. As soon as an appreciable arc of the earth's surface had been spanned it became evident that the radio waves must bend around the earth. MacDonald [1] was one of the first to show that the waves might be refracted sufficiently. This theory criticised, corrected, and finally approved, has been discussed by Rayleigh and Poincaré,[2] also by Poincaré in a series of articles, [3] and by Love.[4] Other equations were developed by Nicholson in a series of papers,[5] and by Rybegynski.[6] Sommerfeldt [7] had introduced a correction term by considering a surface wave at the discontinuity in the specific inductive capacity which occurs at the earth's surface.

All of the comparatively simple theories differed materially in the assumptions made so that the constants differed widely. In one particular, however, they agreed,

[1] Proc. Royal Soc., vol. 71, p. 251, 1903. Proc. Royal Soc., vol. c. 72, p. 59, 1904. Trans. Royal Soc., vol. c. 210, A, p. 113, 1910.
[2] Proc. Royal Soc., vol. 72, A, 1903.
[3] La Lumière Électrique, vol. 42, 1908.
[4] Trans. Royal Soc., vol. 215 A, p. 105 and 125, 1915.
[5] Phil. Mag., vol. 19, 1910.
[6] Ann. der Physik, vol. 41, 1913.
[7] Ann. der Physik, vol. 28, 1909.

in that a damping factor depending on the cube root of the wave length appears. Attempts have been made to verify these equations by Austin[1] and by Fuller.[2] It was found that Austin and Fuller did not agree except that the damping factor contained the square root of the wave length. In that important particular they indicated the error of the equations previously obtained, in which the cube root of the wave length appeared. Further results are given by Hogan,[3] and by Trench,[4] who also failed to agree with previous work.

It should be noted that all of the measurements made were made only during daylight. Radio transmission is much more uniform during the daylight hours, although the waves are damped more rapidly. Marconi[5] first noted this variation, and gave evidence of great irregularity occurring at sunrise and sunset. Eccles[6] has discussed the matter at some length and Fleming has also collected the published information, and discussed the possible causes.[7]

The possibility of interference due to reflections of the electromagnetic waves, which might cause variations in signal strength or audibility, has received particular attention by Marchant[8] and by Eccles.[9]

The possibility of there being a conducting layer has been long recognized, possibly first by Fitzgerald. Dewar[10] also suggested that there might be a region permanently conducting by virtue of a large amount of free ionization. This was brought prominently to the fore by the discussion of Heaviside,[11] and the region is now known as the "Heaviside layer." It is generally assumed to be at an altitude of, about, 80 km. This lower limit is somewhat below the point at which the Aurora Polaris appears, which has now been fixed by Störmer.[12] and Vegard and Krogness[13] at possibly 85 km. with maxima at 100 km. and 106 km. It has been shown by Campbell[14] that the prominent green auroral line at .5770 μ is always present in the light from the sky. Undoubtedly, the effect of ultra-violet light in the sun's radiation very materially increases the ionization of the air and carries the ionization region due to this cause much below the layer of permanent ionization. It has been observed by Elihu Thompson[15] that violent auroral displays are accompanied by large induced potentials on telegraph lines, and at such times an unusually high state of electrification of the atmosphere exists. No exact determination of the effect of such electrical activity on radio transmission has yet been made. The cable companies report large earth currents during the time of auroral display.

The velocity of the electromagnetic wave has been measured, by a method having an accuracy in the time measurements within 1/100,000 second between the Eiffel Tower and Arlington, by Abraham, Dufour, and Ferrie.[16] It has been found that the time first obtained was 0.033 second and again 0.022 second. This difference was far above the experimental error and indicated a large change in the velocity of the electromagnetic wave. It is significant that the velocity was considerably below that of light. One of the authors reported that the most probable value could be explained on the assumption that, the path of the wave was at a height above the earth of 50 km. This suggests that the Heaviside layer at 80 km. plays an important rôle.

It is therefore probable that the electromagnetic waves can be transmitted around the earth between the Heaviside layer and the earth as between two conducting surfaces. This would be particularly true at night, while during the daytime the intervening space would have large ionization well distributed. It has been pointed out by Eccles[1] that although the conducting surface of the Heaviside layer has been lost by the added ionization due to the sunlight, still the waves can be transmitted around the earth by the refraction thereby resulting. This possibility is argued at length since previous theories had not taken this view of the effect of the distributed ionization. The influence of water vapor has generally been neglected, but Schwers[2] shows that it might alone account for the refraction of the wave around the earth. He states, however, that probably the ionization of the air is of more importance.

The transmission of radio signals can occur over extraordinary distances, such as the reception in Australia of messages from Carnarvan, England, a distance of approximately 19,000 km. (12,000 miles) when the receiving station used a low antenna and a one-stage amplifier. This result was repeatedly obtained for several months, during the winter of 1917. Other cases where even more astonishing results, of 8,000 km., when only a 2 kw. transmitter is used, have been frequently reported. Such results are usually classed as freak performances, but they are none the less real and must be provided for in any general theory of radio transmission.

The foregoing facts, well known to radio engineers, are given with great brevity and the proposed theories have been pointed out. It must be evident that an adequate theory of the transmission of radio signals must explain all of the established facts, such as—

(1) The difference between daylight and night transmission.

(2) Irregularities occurring at sunrise and sunset.

(3) Special irregularities such as might be caused by interference.

(4) The phenomena of direction changes in the electromagnetic wave, with the experimental determination of which, the body of this paper is concerned.

The direction changes play an important part in the phenomena of the transmission of electromagnetic waves, which has been found to be so complex. It is also of great practical importance to determine to what extent the direction of radio signals as measured by the radio goniometer can be depended on, since the proposed radio "lighthouses" might be a source of danger instead of safety. Changes of audibility have also been obtained so as to determine whether or not there is any relation between the two.

The causes for the departure from the normal direction of the transmission of radio signals as well as their varying audibility can be expected to be explainable on a basis of changes in the uniformity of the transmitting medium. This will be considered at some length for the purpose of determining whether or not the physical conditions existing afford the necessary discontinuities to explain the variations observed.

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[1] Bul. Bureau of Stand., vol. 7, p. 315, 1911. Bul. Bureau of Stand., vol. 2, No. 1, p. 81, 1914. Proc. Inst. Radio Eng., vol. 3, June, 1915. Jour. Franklin Inst., November, 1916.
[2] Proc. Am. Inst. Elect. Eng., April, 1915.
[3] Electrician, vol. 71, p. 720, 1913.
[4] Electrician, vol. 79, pp. 102, 147, and 181, 1917.
[5] Proc. Roy. Soc., June, 1902; Proc. Roy. Inst., 1911.
[6] Proc. Roy. Soc., vol. 87, A, p. 79, 1912.
[7] Wireless Telegraphy, p. 843. Electrician, vol. 74, p. 152.
[8] Proc. Inst. Radio Eng., p. 512, 1916.
[9] Proc. Roy. Inst., vol. 87, 1912.
[10] Proc. Roy. Inst., vol. 17, p. 223, 1902.
[11] Electrical Papers, vol. 2, p. 152.
[12] Terr. Magnet and Atmos. Elect., vol. 21, p. 157, 1916.
[13] Terr. Magnet and Atmos. Elect., vol. 21, p. 169, 1916.
[14] Astrophr. Jour. 2, 162, 1895.
[15] Proc. Nat. Acad. of Sci., vol. 3, January, 1917.
[16] Compt. Rend., vol. 159, p. 38, July 6, 1914.

[1] Proc. Roy. Soc., vol. 87, A., p. 79, 1912. Electrician, p. 1015, Sept. 27, 1912.
[2] Proc. Phys. Soc. of London, vol. 29, pt. 2, Feb. 15, 1917.

METHODS AND RESULTS OF RADIO TESTS.[1]

For the measurement of the direction of propagation of the wave received at any station (see fig. 1), a loop was employed which could be freely rotated about a vertical axis. If the wave-front is vertical, the loop, rotated about a vertical axis, will have a maximum potential difference across its terminals when its plane is at right angles to the wave front. This results in a maximum strength of signal. When the plane of the

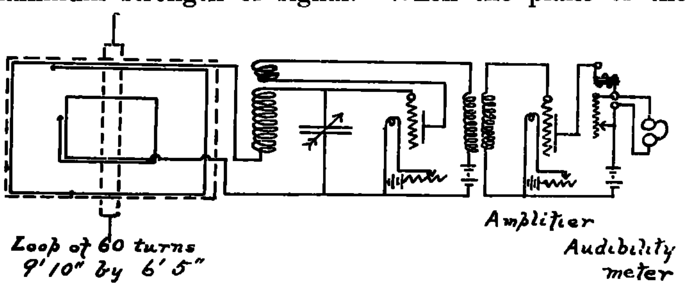

FIG. 1.—Audibility meter.

loop is parallel to the wave front, there is no current set up in the oscillating circuit, composed of the loop and the tuning condenser, which results in complete silence in the receiving telephone. If the loop is rotated about a horizontal axis, there is no change in the audibility of the signals in the receiving telephone.

The loop used at Houlton, Me., for these measurements is as follows: Sixty turns, No. 26, B. & S. solid copper wire, D. C. C. wound in one plane with horizontal wires spaced 0.4 inch and vertical wires 0.6 inch apart. The outside dimensions of the loop are, therefore, vertically 6 feet 5 inches, and horizontally 9 feet 10 inches. The loop was 7½ inches below the ceiling and 9 inches above the floor, having a clearance of 6 inches at one point from the wall and 12 inches at the other, in a room on the lower floor of a small detached wooden house. The vertical axis about which the loop was turned was pivoted to floor and ceiling.

Figure 2 gives a polar curve of audibility changes as the receiving loop is rotated. This curve is thoroughly

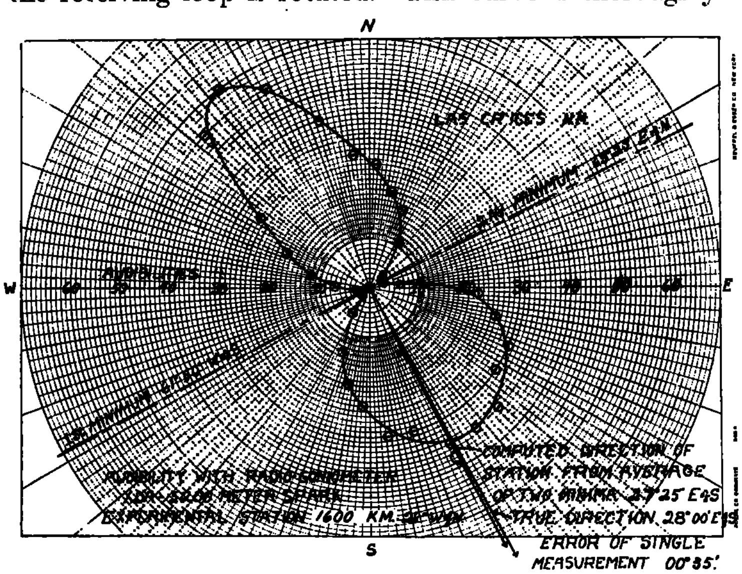

FIG. 2.—Polar curve of audibility.

characteristic. The difference in its upper and lower part is due to the design of the loop which was purposely constructed so as to indicate the absolute direction of the radio signals. It has been found from many tests that the minima lie 90° from the direction of transmitting station, using normal daylight conditions. It is to be noted that this is true even though the maximum

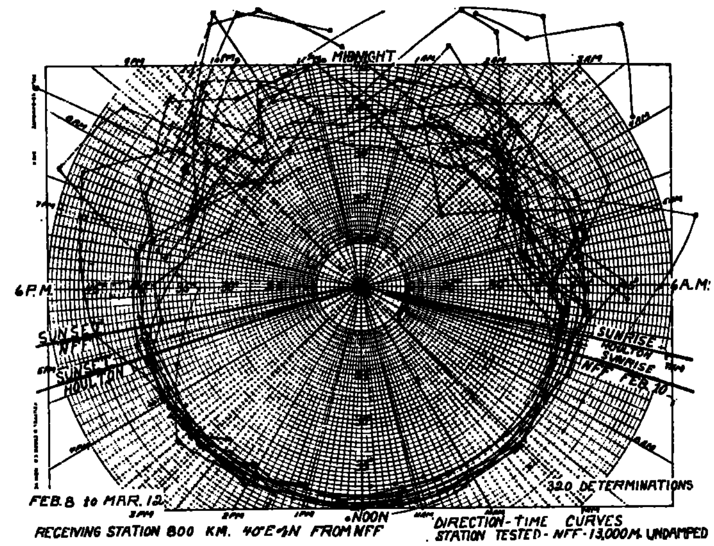

FIG. 3.

vector does not lie along this direction. In the figure shown a difference of about 10° will be noted while the direction of the transmitting station as computed from the minimum values is in error by only 35′.

Figure 3 gives a series of direction determinations made as described above and each direction is the result of a computation from the accurate determination of the minima of a polar curve, each of which required nine audibility readings. It will be noted that during the sunlight hours the direction measurements varied but little and the values could be used for determining the location of the transmitting station. During the night, however, the direction measurements showed extremely erratic values.

Figure 4 is drawn from a continuous series of observations made during one week. The same methods were employed as just described.

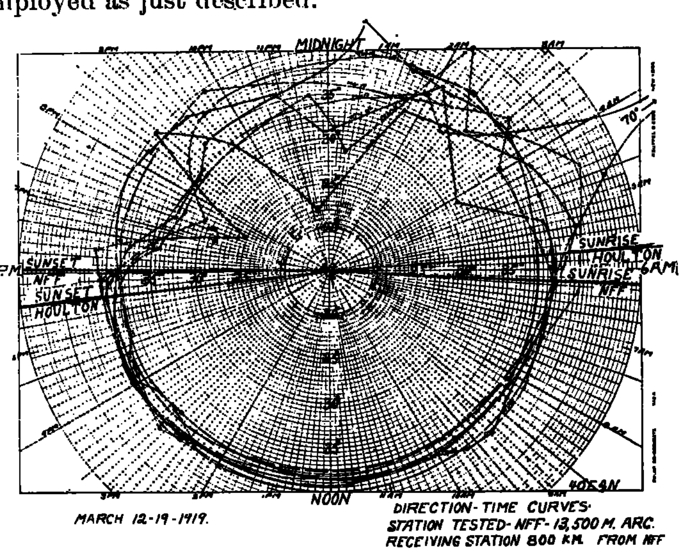

FIG. 4.

It is particularly noted that all of the cases observed when no directional measurements could be made ap-

[1] Abstracted from the original.—C. L. M.

peared during the night, and also, in the large majority of them, bad weather conditions prevailed.

Figure 5 gives all of the directions obtained during the particular seven hours when occurred the widest variation noted during the week's test shown in figure 4. In a figure there are plotted in two instances the data employed in computing one of the two minima, the average of which gives a single point on the curve of this figure, taken March 19. There was no rain at Houlton, but there was rain in every other town in Maine on Weather Bureau list.

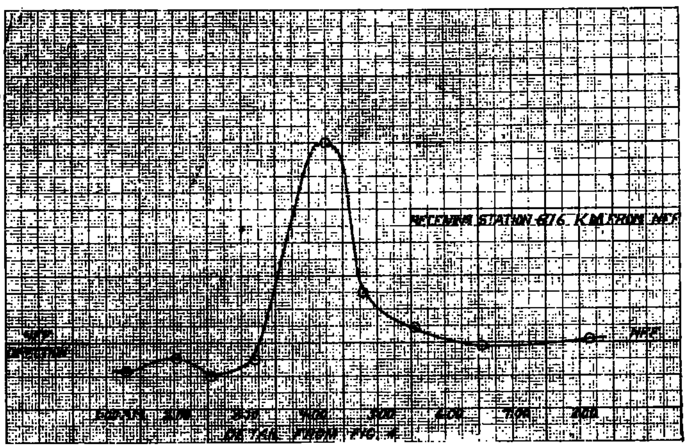

FIG. 5.—Detail from fig. 4.

Figure 6 illustrates the phenomenon often observed and known as "swinging" of the audibility. The audibility measurements were made by the shunted telephone method and thus varied by steps of considerable magnitude. That is the cause of many of the observations showing exactly the same audibility, while a more accurate method would have distributed the values.

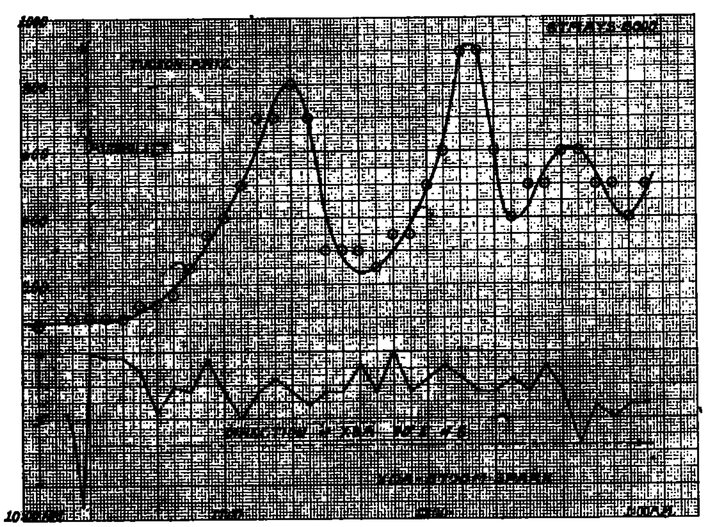

FIG. 6.—"Swinging" of audibility.

These observations were taken June 16–17 at Tucson, Ariz. The sky was clear but the strays were reported as heavy.

During the time covered by these observations, there was but little change in the direction measurements, and the only rapid change in direction noted, occurred during the time that the audibility of the signal was constant.

It should be stated that the audibility measurements were made not with the use of the loop, but instead by using a vertical antenna which was located at more than 0.2 km. from the loop station. It was proved by experiments, that no interference existed between the two receiving stations, one independently employed in making audibility measurements, and the other in determining by the loop the direction of the radio transmission.

In the following figure the same methods outlined above for determining audibility of the signals and the directional measurements were employed.

Figure 7 primarily intended to show that the same station may exhibit widely fluctuation values of audibility with negligible changes in direction, and also the converse of large and rapid changes in direction with inconsiderable changes in audibility.

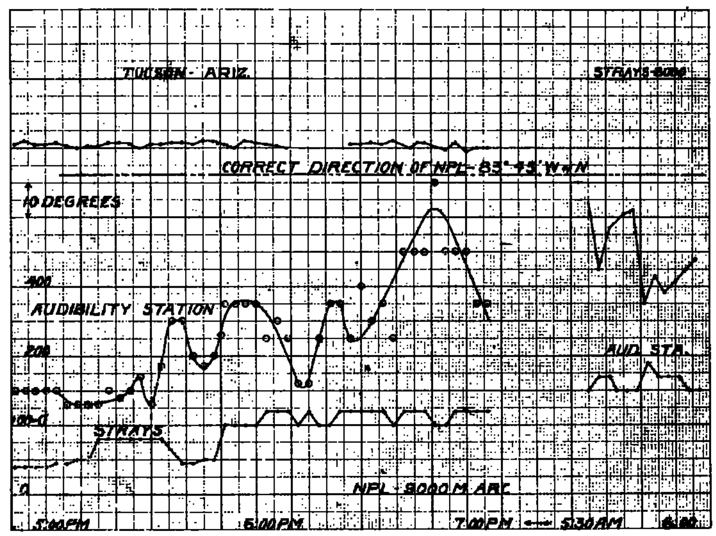

FIG. 7.

There are shown also in this figure values for strays which in the first case were comparatively low, and in the second were extraordinarily high. It is believed however that the presence of high strays is no indication of excessive changes in audibility.

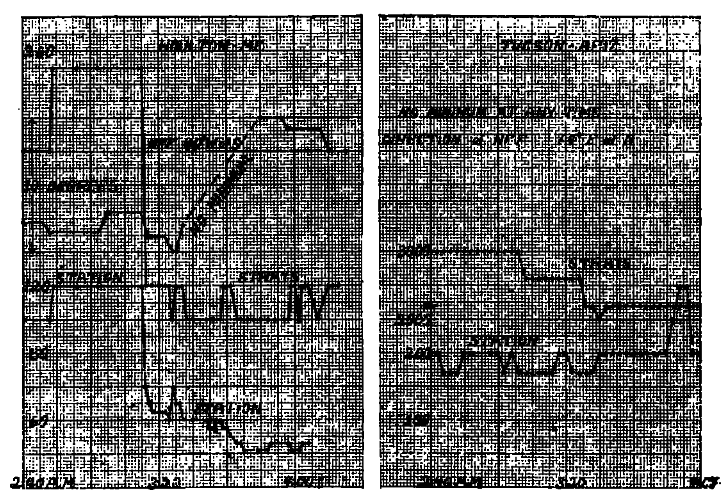

FIG. 8.—Showing complete loss of directional effect.

Figure 8 illustrates a very special case where the radiogoniometer loop exhibited no directional effect when rotated about a vertical axis. At the same time the same transmitting station was observed at both Tucson, Ariz., and Houlton, Me., and throughout the whole period at Tucson no direction could be obtained. The weather condition at Houlton, Me., was overcast sky but no rain, while at Tucson, Ariz., there were bad static conditions, with lightning around the horizon but with no precipitation of rain during the day, July 11.

The observation at Houlton, Me., showed uniform direction measurements somewhat displaced from normal, and with a broadening of the minimum. This means that the changes of audibility in the neighborhood of the minimum position of the loop, as the loop is rotating, was less rapid than normal and also with a maximum audibility of the usual value it would be found that the signals did not completely disappear when the loop was in the condition showing the minimum audibility. Frequently it is necessary to determine the position of the loop for minimum, by a single observation under these special conditions, since there is no complete disappearance of the signal as the loop approaches its position for minimum audibility.

When the special condition of "no minimum" is observed, then the loop may be rotated about its vertical axis without any appreciable change in audibility. The explanation of this condition is given in a subsequent paragraph.

In the preceding figures there are shown observations from all types of transmitters as received at stations varying widely in latitude, in longitude, and in character of terrain. The wave lengths employed varied also through a wide range. The transmission has been over long and short distances and over land and water. It will be seen that in no case are the waves free from distortion as well as from audibility variations.

It will be pointed out in a later section that certain possible explanations of the observed phenomena require the interference between portions of the wave traveling somewhat different paths. The conditions therefore must be such that the interference can take place even when the wave length is short and the wave train is the damped one given by a spark system.

TABLES.

NO MINIMUM AUDIBILITY AS RADIOGONIOMETER LOOP WAS ROTATED ABOUT A VERTICAL AXIS.

No. 1.

HOULTON, ME., *March 6 and 7, 1919.*

1 A. M. TO 7 A. M., MARCH 7, 1919. SERGT. HEINLINE.

1.15–1.28 a. m.—NFF. 36° east of south.
2.00–2.10.

NOTE.—Took readings on NFF and NSS and plotted curves for same. While reading NFF from 2 a. m. could find no minimum point, audibility being practically level at all points of the compass. Reading taken on NSS immediately after showed normal conditions for that station, while NFF continued flat.

2.10–2.24 a. m.—NSS 42° 30′.
3.12–3.25 a. m.—NFF 27° 00′.
3.27–3.36 a. m.—NSS 43° 45′.
4.45–4.55 a. m.—NFF 41° 45′.

Weather conditions were unsettled. March 6, rain 0.20 inch; March 7, rain 0.10 inch.

NFF is New Brunswick, N. J., employing a machine transmitter giving undamped waves of 13,500 meters.

NSS is Annapolis, Md., employing a large arc transmitter giving undamped waves of various lengths reported to have been 15,000 meters at this time.

No. 2.

HOULTON, ME., *6 p. m., April 24, to 1 a. m., April 25, 1919.*

SERGTS. PFEIFFER AND M'ALLISTER.

Glace Bay, GB, with 8,000-meter spark.

10.24 p. m.—12° 30′; 11.02 p. m.—12° 30′.
10.43 p. m.—12° 30′; 11.20 p. m.—12° 30′.

Arlington, NAA, with 2,500-meter spark.

11.30 p. m.

NOTE.—NAA was tuned in on both of the loop receiving sets, but in neither case was it found possible to get definite disappearing points.

Mexico City, XDA, with 5,700-meter spark.

11.38 p. m.—27° 30′ west of north; 11.59 p. m.—25° 0′.
11.49 p. m.—27° 30′ west of north; 12.01 a. m.—42° 30′.
11.50 p. m.—29° 0′ west of north; 12.25, no minimum.

NOTE.—Disappearing points began to spread and in next minute no minimum points could be distinguished. This condition continued until 12.32 a. m., when it quickly changed and the following readings were taken:

12.34 a. m.—26° 0′; 12.52 a. m.—26° 0′ west of north.

Weather conditions were unsettled and traces of rain fell on the 24th and 25th about one-third of an inch.

NOTE.—In both No. 1 and No. 2 it is of importance to note that while certain stations gave *no minimum* reading when the radiogoniometer loop was rotated about its vertical axis, other stations gave good direction measurements.

No. 3.

HOULTON, ME., *July 11, 1919, 1 to 8 a. m.*

M.S.E. PFEIFFER.

New Brunswick, N. S., NFF with 13,500 meter undamped wave.

3.50 a. m.—35° 30′; 3.24 a. m.—32° 30′; minimum points much broader.
3.17 a. m.—33° 45′; 3.27 a. m.—34° 30′, minimum points broad.

NOTE.—From 3.33 a. m. to 3.58 a. m. the minimum points were too broad for a reading.

3.50 a. m.—42° 30′, minimum points sharp.
3.59 a. m.—41° 45′, normal.

Weather: Overcast, light south breeze, cool; no rain.

No. 4.

TUCSON, ARIZ., *July 11, 1919, 8 a. m. to 4 p. m.*

CORP. WM. F. AUFENANGER.

New Brunswick, N. S., NFF, with 13,500 meter undamped wave.

NOTE.—NFF heard from about 3 a. m. to end of watch, but was very weak. During transmitting periods neither Capt. Ives nor operator could discern any disappearing points, as signals were faintly audible over entire 360°. Weather and static conditions unusually bad, lightning continuously playing around horizon.

No. 5.

HOULTON, ME., *July 13, 1919, 1 to 8 a. m.*

M.S.E. PFEIFFER.

New Brunswick, N. S., NFF, with 13,500 meter undamped wave.

3.20 a. m.—43° 30′, broad minimum; 4.02 a. m.—41° 0′, sharper minimum.
3.57 a. m.—42° 0′, broad minimum; 4.07 a. m.—44° 0′ broad minimum.
4.29—No reading. Note: Minimum points too broad for reading.
4.39—No reading. Note: Minimum points hardly discernible, apparently being around due east and west.
4.47—No reading. Note: Minimum points continually changing, but very indefinite, now being around due north and south.
4.49—55° 0′, broad minimum; 4.57 a. m., 44° 30′, sharp minimum.
4.52—48° 0′, slightly sharper.

Weather: Clear, cool, full moon.

It is particularly noted that all of the cases observed when no directional measurements could be made apppeared during the night, and also in the large majority of them bad weather conditions prevailed.

DISCUSSION OF RESULTS.

It has been shown that radio telegraphic signals of all kinds, including transmitters employing high-frequency alternators and arcs, giving undamped waves of 4,900 to 17,300 meters length, and various spark systems having damped waves from 960 to 5,700 meters wave length, suffer distortions whether transmission is over land or over water. Many observations have been taken which are not shown in the figures, covering a distance range from 65 km. (Annapolis, 17,300 meter arc received at Washington) to 12,000 km. (Funabashi, 3,800 meter spark, received at McAllen, Tex.). In all cases, neither the character of the transmitter, the wave length employed nor the local conditions of terrain have been effective in preventing the distortion of the electromagnetic wave used in signaling.

The changes in audibility have also been obtained by an extended series of experiments, but the figures presented show only a few particular cases where it is desired to bring out the fact that large changes in direction are not necessarily accompanied by any considerable changes in audibility of the signals and that even an entire loss of directional effect by the receiving loop may occur with no considerable change of any character in the audibility of the signals.

The converse may also be true and it is shown that there may be very large changes in the audibility of the signals without any appreciable change in the direction.

In general, it can be said that the changes in audibility are of much more frequent occurrence and are proportionately much larger than the changes in direction. It seems, also that the audibility changes follow a diurnal cycle as well as a seasonal cycle. Probably the underlying causes for the two changes are the same, but the directional changes only occur when the underlying causes produce a very special condition which does not have any considerable effect upon the energy absorption.

It might be expected, therefore, that most audibility variations would be produced by changes in the energy absorbed by the transmitting medium and more rarely by interference phenomena when the ionization causing absorption in general is so concentrated and segregated as to produce sharply defined conducting strata; this would act as a reflector for the electromagnetic waves under conditions where the difference in path between a direct and reflected wave would be at most only a few half-wave lengths, and the angle would be small between the reflected and direct wave. The change in directional effect might be produced by the combination at the receiver of a direct and a reflected wave, but it would be necessary for the reflection to take place from a surface sufficiently removed in a horizontal direction from the receiver that the reflected wave would have a very considerable horizontal component in order to cause the loop turning about a vertical axis to give an indication of a directional change.

In the second class of directional changes it is assumed that there are two components which have a quadrature relation both with respect to time and direction. This would require a reflected wave, as indicated above, from a surface at a considerable distance in a horizontal direction from the receiver and at a distance which would make the reflected electromagnetic wave 90° out of phase with the direct wave. If the distance were such that this phase difference was not 90° then the resultant wave at the receiver would show a direction depending upon the composition of the direct and reflected wave with respect to amplitude and direction. The phase combination of this reflected and direct wave might be almost anything, but would not affect the audibility of the signals as received by the loop, and so would not affect the general measurements upon which the direction indications depend.

We need now to examine with care the complex state existing in the atmosphere through which the electromagnetic waves travel in order to determine the physical conditions upon which depend the observed phenomena of the direction changes and variations of audibility and strays.

The latest information that we have in regard to the condition of the atmosphere shows that there are certain regions where there are discontinuities such as to make possible the formation of reflecting surfaces, assumed in our explanation of the observed phenomena. There are—

First. The Heaviside layer, assumed to be about 80 km. above the surface of the earth, which has been discussed at considerable length by previous investigators.

There seems to be no doubt but that there would be a discontinuity and that it might very well happen that it would be much more pronounced during the night than during the daytime, when the ionization produced by the sun's light might be expected to extend below the stratum of permanent ionization, diminishing rapidly as we proceed into the lower atmosphere. It might very well be that the greater transmitting distances observed during the night are obtained by the passage of the electromagnetic waves between the conducting surface of the earth and the conducting region of the Heaviside layer, which being a region of permanent ionization has a lower surface showing a sharp discontinuity, as soon as the ionization stops upon the disappearance of the sun and the ions present have rapidly recombined. There would then, within this region below the Heaviside layer, be comparatively little free ionization and consequently but little absorption, allowing thus the transmission of radio signals over excessively long distances. During the daytime the widely distributed ionization caused by the sunlight would result in large absorption of the energy, and this condition would be generally found to exist at all points. Irregularities in recombination at the disappearance of the sunlight might very well produce large regions in which the uniformity of the conducting layer is broken and where there persists for a time absorbing regions which would have considerable effect upon the audibility of the signals and an erratic effect, as is usually observed in the case of the reception at night of radio signals.

The possibility of reflection from these large ionized masses or from the Heaviside layer itself in such a way as to produce the interference phenomenon, which has long been known to the radio engineer as a "swinging" and "fading" of the radio signals at night, has been examined in detail by a number of engineers, and their conclusion will be found in the literature on the subject. It does not seem to us that it would be possible to have an interference produced by these reflections at the receiver, since the number of half-wave lengths difference between the two paths necessary in order to account for the observed phenomena would be so great as to make any sharply defined interference pattern out of the question, considering the nature of the reflecting surfaces and the characteristics of the transmitting medium. This would also be even more evident in the case of the changes of direction, since the distance would be very considerably greater on account of the necessity for having the horizontal component needed to explain the observed angular displacement of the direction of the wave.

Second. The diurnal vertical convection is limited to from 500 to 1,000 meters above the surface of the earth, depending upon the season of the year and the condition of the weather.

There would be a discontinuity which would appear at about the place where the measurements of penetrating radiation have shown that the effect of the radioactive constituents of the earth disappears. It does not seem to us that this would be a sufficiently well-defined discontinuity to account for the reflecting strata needed to account for the observed phenomena.

Third. There is, during the summer, a region which is defined by the cumulus clouds at 4 or 5 km. above the earth. We do not believe that this discontinuity is sufficient to account for the results.

Fourth. There is, at an elevation of approximately 7 km., a region known as the alto-stratus layer, which is present in both summer and winter. This layer is not sufficiently well defined, and the causes for the discontinuity are not such as to lead us to believe that the observed phenomena can be accounted for by any reflections at this altitude.

Fifth. There is always found a sharp dividing line between the troposphere and the stratosphere (isothermal layer) which occurs at an average altitude of 10 km. This is dependent somewhat upon the season and also the storm areas. It is found that changes as large as 3 km. may exist between the cyclonic and anticyclonic regions. At this sharply marked boundary there is undoubtedly a layer of cosmic dust which may very well be strongly radioactive. This is also the region where the cirrus clouds usually form, and which is consistently their upper limit. It is the most sharply marked discontinuity of which we have any definite knowledge in the upper atmosphere.

It is probable that such a stratum is present during the night when there is little movement in the upper part of the troposphere and that this conducting layer forming the boundary between the troposphere and stratosphere, will act as an excellent reflector. The movement caused by a cyclonic disturbance will change, however, the inclination of this conducting layer. There may also be considerable regions in the part of the troposphere bordering on its discontinuity which are strongly ionized, due to the upward drift of the negatively charged particles and water vapor which have been segregated in sufficiently large quantity so as not to be immediately neutralized after the disappearance of sunlight. The cessation of the turmoil resulting from the convection currents caused by the sun's action will allow these ionized regions to assume a stratified form which will act as excellent reflecting surfaces.

A soon as the sun reappears and covection currents are reestablished, they both destroy the sharply defined conducting layer and cause a widely distributed ionization which absorbs much of the available energy. The result is a decrease in signal strength, but no considerable distortion in the direction of the transmission.

During the night the long-distance transmission could take place between the earth and the Heaviside layer with the intermediate conducting stratum at approximately 10 km. above the earth's surface, playing but little part until some discontinuity caused it to act as a reflector. This conducting layer would also make possible abrupt local changes in energy due to absorption which would later be equalized by a gradual distribution through the conducting layer, which is, of course, not perfect, from the region lying between it and the Heaviside layer.

During the daytime the greater ionization and its wide distribution below the Heaviside layer, as well as the constant occurrence of ionization below the stratosphere, would both tend to absorb the energy of the electromagnetic wave, and so decrease the observed signal strength at the receiving station, while preventing the reflections necessary for the distortions observed during the night.

In the same way also the periodic change in audibility or "swinging" may be due to the movement of interposed conducting masses of air which absorb the energy of the wave. This would be particularly true when the periodic change occurs through a considerable time. The interposition of a series of storm regions moving along the same direction would produce such changes in audibility. A test of this might be the determination of such variations with respect to a north and south line and an east and west line, since there is a decidedly greater storm movement along the east and west line.

There is consequently the condition necessary for reflection from the stratum which is approximately 10 km. above the surface of the earth. The distance is such that it will permit the formation of interference patterns at the receiving station, since the number of half waves would not be too large to make that possible. This might occur quite rapidly and be due to the interference of a direct and reflected wave when the reflecting surface is changing its position with a velocity often found in the movement of cloud masses. The entire disappearance of directional effect when due to the rotation of the electromagnetic field would also be easily possible when the reflection occurs from the ionized layer between the troposphere and stratosphere or from an ionized stratum below that boundary.

It would be expected that the changes in direction would occur therefore, only when the discontinuity due to the stratification of the ionized gases and particles became effective during the night hours, and that these changes in direction would be produced only by reflection and never to any appreciable extent by a refraction, so that changes of small amount might be expected to be of frequent occurrence, while changes of large amount requiring a reflection from a surface beyond the receiving station, so as to allow the resultant direction caused by the combination of the reflected and direct waves to make a shift as great as the change of 56° 30′ in 13 minutes, as shown, would be of much more infrequent occurrence than the audibility changes continually observed. Also the very special case where there is a complete disappearance of directional effect would not be produced except under very special circumstances which might not be expected to occur except at rather infrequent intervals.

The results obtained have been quite disconcerting to those of us interested in making a quantitative use of the directional characteristics of the loop, but it is believed that a knowledge of what may occur, although rarely, will be of material assistance in further work. It is possible also that our knowledge of the upper atmosphere may be greatly advanced by a systematic employment of high frequency oscillations and the use of quantitative methods in radio measurements.